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New York Area Control Facility/Metroplex Control Facility Vulnerability Analysis

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16. Abstract

This report contains the results of an analysis of the impact of a New York Area Control Facility (ACF) or Metroplex Control Facility (MCF) failure under three different MCF configurations. This analysis was conducted using the National Airspace System Performance Analysis Capability (NASPAC) simulation model to assist ATR-310 and the Eastern Region on defining end-state configurations for the New York ACF/MCF. This report includes a discussion of the facilities and procedures involved in an ACF/MCF failure, the analysis approach, and the results of the analysis.

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EXECUTIVE SUMMARY

This report documents the results of a study simulating the capacity effects of a New York Area Control Facility (ACF) or Metroplex Control Facility (MCF) failure. The main objective was to evaluate alternative MCF configurations from the standpoint of delays resulting from a total facility failure. Both ACF and MCF failures were simulated under three different MCF configurations. Configuration 1 consisted of the New York Terminal Radar Approach Control (TRACON) (N90). Configuration 2 consisted of the N90 TRACON as well as Philadelphia (PHL), Allentown (ABE), and McGuire AFB (WRI). Configuration 3 included N90, ABE, PHL, WRI with the addition of Wilkes-Barre (AVP) and Reading (RDG). An analysis was conducted using the National Airspace System Performance Analysis Capability (NASPAC) simulation model. This effort was to assist ATR-310 and the Eastern Region in defining end-state configurations for the New York ACF/MCF.

For both an ACF and MCF failure, boundary restrictions were used to restrict airspace capacity. The capacity values and sequence of failure events were based on the recommendations of representatives from the New York and adjacent Air Route Traffic Control Centers (ARTCCs) and TRACONs, as well as ATR-310 and AOR-100. NASPAC results are very sensitive to these parameters and assumptions.

The results are consistent with expectations based on the assumptions used in the model. As expected, for the MCF failure, a larger MCF configuration results in greater delays. Given an ACF failure, the opposite is true: size of MCF and delays are inversely related. The effects of a New York MCF failure were shown to be more catastrophic than an ACF failure. This is a result of the very low post-failure capacity of the airspace after the MCF fails and the persistence of the effects beyond the short-term. It is recommended that decisions regarding future facility planning in the New York area take this into consideration. The operational and environmental factors that generated the limiting capacity values in the MCF failure merit further examination.

The key factor separating the configurations is the inclusion or exclusion of Philadelphia TRACON from the MCF. For both types of facility failure, major differences emerged between Configurations 1 and 2, with very little difference separating Configurations 2 and 3. However, since the MCF failure was found to be the more catastrophic case, a strategy of minimizing failure effects would imply that a smaller MCF is better.

Therefore, under the constraints and assumptions of this study, N90 by itself is the least vulnerable of the three MCF configurations considered.

1. INTRODUCTION.

1.1 PURPOSE AND SCOPE.

The purpose of this document is to present the results of a study investigating the effects of a New York Area Control Facility (ACF) or Metroplex Control Facility (MCF) failure on system-wide air traffic throughput. The Federal Aviation Administration (FAA) plans to combine existing en route and terminal control facilities into ACFs. Some larger terminal control facilities, such as New York (N90), may be left as stand-alone facilities called Metroplex Control Facilities (MCF). An analysis was conducted of ACF and MCF failures using the National Airspace System Performance Analysis Capability (NASPAC) simulation model to assist ATR-310 and the Eastern Region in defining end-state configurations for the New York ACF/MCF. This analysis was sponsored by the FAA's Operations Research Service (AOR) and conducted by the ATC Technology Branch (ACD-340) at the FAA Technical Center. This report includes a discussion of the facilities and procedures involved in an ACF/MCF failure, the analysis approach, and the results of the analysis.

1.2 ANALYSIS OBJECTIVES.

This study was designed to answer the following questions:

a. What are the effects of different MCF configurations on MCF and ACF failures?

b. What is the impact of a total ACF failure on the New York airspace, on the adjacent airspace and on the entire National Airspace System (NAS)?

c. What is the impact of a total MCF failure on the New York airspace, on the adjacent airspace and on the entire NAS?

1.3 REPORT ORGANIZATION.

Section 2 of this report provides background material on the ACF and MCF concepts, the NASPAC simulation model, and a previous NASPAC analysis of the proposed Chicago ACF. Section 3 presents the approach and assumptions used for the analysis including the plans to be followed in the event of a New York ACF or MCF failure. Section 4 outlines the detailed methodology and discusses the performance metrics employed. Section 5 presents the analysis results and conclusions.

2. BACKGROUND.

2.1 AREA CONTROL FACILITIES (ACFS).

The ACF concept was originally introduced in the NAS Plan as part of the Advanced Automation System (AAS) [1]. An ACF will

consolidate Air Route Traffic Control Center (ARTCC) and Terminal Radar Approach Control (TRACON) functions into a single facility. An ACF will differ from an ARTCC by including a new generation of equipment and software with the ability to perform additional functions. ACFs will minimize the costs that would be incurred if identical advanced automated systems were provided to a large number of facilities. This project will produce a higher level of safety, operational efficiency, and increased ability to absorb traffic growth.

2.2 METROPLEX CONTROL FACILITIES (MCFS).

The FAA is concerned about the vulnerability of the NAS to an ACF failure and in particular the potential disruption to air traffic such an event would produce. The need to reduce the vulnerability of the system to this type of failure was one of the motives for introducing the MCF concept. Instead of placing all terminal facilities in the ACF, a separate MCF would provide a consolidation of several of the TRACONs in a large metropolitan area. In the event of an ACF failure, an MCF will remain operational. An MCF will resemble a present-day TRACON, but will be equipped with a new generation of computers and other related systems, and will control a larger area of airspace around a terminal area.

2.3 THE NASPAC SIMULATION MODEL.

The NASPAC simulation model was developed by The MITRE Corporation for the FAA as a simulation tool to analyze the performance of the NAS. NASPAC is used to study the system-wide performance of the NAS and to provide a quantitative foundation for making decisions related to system improvements and management. The model can be used to identify air-traffic flow congestion problems, evaluate solutions, and support strategic planning. The NASPAC simulation model can be used to analyze, in the aggregate, the major effects of interactions among the many components of the airspace system. In particular, the model is used to study how delay ripples through the system and how the system will react to projected demand and capacity changes.

NASPAC is a macro model and is used to analyze NAS-wide impacts of proposed changes. Analysis of capacity effects at a lower level of detail requires additional executions of the simulation model to achieve statistically reliable results. Operations at individual airports and terminal areas are not modeled in detail. Airport capacities are represented by a range of values derived from many sources, including tower personnel. NASPAC does not generally model dynamic aspects of the NAS environment nor specific aircraft speed or vector changes.

2.4 THE CHICAGO ACF BACKUP STUDY.

The MITRE Corporation previously conducted a Chicago ACF/MCF study using the NASPAC simulation model [2]. The objective of the study was to determine the benefits of having an MCF during an ACF failure. The study also measured the quantitative effects of an ACF failure in terms of the delay and number of cancellations generated. The study was completed and a report was issued in September 1990.

In conducting this study, airport capacity values were used to model MCF airspace capacities. Traffic flow restrictions at the ACF boundary were used to simulate the reduced capacity in the airspace of the failed ACF. Sector capacity values were not used for ACF airspace capacity definition. Ongoing NASPAC refinements include an effort to obtain sector capacity estimates which are more accurate or better suited to the model.[1] MITRE previously reported a sector deadlock problem and has generally not used sector capacities in its NASPAC-based studies.

The Chicago study design examined an ACF failure with and without an MCF. The New York study differed from the Chicago study in several respects. The New York airspace is very complex and provides modeling challenges. In addition to an ACF failure, this study also simulated an MCF failure and considered alternative configurations for the MCF airspace.

2.5 NEW YORK ACF/MCF MODELING CONCEPTS.

A vulnerability analysis of the New York ACF and MCF facilities was undertaken to help determine the optimal configuration for the New York MCF, and the impacts of a facility failure on the neighboring facilities and on the NAS as a whole. The study was conducted by the FAA Technical Center.

This analysis was performed using the NASPAC simulation model. NASPAC normally uses capacity values to define the number of aircraft that can be managed through the system, but does not explicitly model terminal airspace. Constraining airport capacity is one way to model terminal airspace failure (as done by MITRE in the Chicago ACF Study). When an MCF fails, the airspace surrounding an airport cannot feed aircraft to that airport. Arrival capacities must reflect the surrounding airspace's ability to feed aircraft to an airport. Departure capacities must reflect the surrounding airspace's ability to manage departing traffic. The airport capacity value must be the minimum of the airport or the terminal airspace capacity.

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1 Improved sector capacity values are planned for the next version of NASPAC, Release R2.

The N90 airspace is very large and complex. Only about 50-60 percent (3200-3500 out of 6000 daily operations) of the traffic handled by N90 actually lands at John F. Kennedy Airport (JFK), LaGuardia Airport (LGA), or Newark (EWR). The remainder are overflights or flights to various satellite airports.

"Restricting the airport arrival rates to simulate the reduced capacity caused by an MCF failure will not restrict a large portion of the traffic handled by N90."

Given the limitations in using airport capacity as a surrogate measure of the terminal airspace capacity, it was decided to try an alternative modeling scheme. Modifications were made to NASPAC to allow the modeling of both the ACF and MCF airspace via restriction boundaries. Restriction boundaries were drawn around the defined airspace, allowing complete control over the aircraft entering and exiting the airspace. Though it increased the complexity of the modeling process, this approach allowed greater flexibility in scenario definition and provided more consistency in modeling methodology for both the ACF and MCF failure scenarios.

Both of the above methods were employed in this analysis to model the MCF configurations. The first method was employed in the Chicago ACF study and was the method initially used in this study. The use of the restriction boundary for the MCF was deemed a more consistent modeling approach and was the preferred approach for this analysis. Results of both modeling schemes are provided; results and conclusions remain the same.

3. APPROACH.

3.1 OVERVIEW.

The overall approach followed was to model the ACF and MCF failure events by reducing the capacity of the corresponding resources and observing the effects on system throughput. Key features of the New York ACF/MCF airspace geometry were modeled within the context of the entire system. As with any model, elements of the real system were abstracted for the purposes of the simulation.

The following sections contain background information and describe plans in the event of a New York ACF and MCF failure. The scenario definitions and details for modeling these events follow. Finally, a list of assumptions used in this study is given.

3.2 NEW YORK ACF FAILURE.

Air traffic control (ATC) in the New York vicinity is characterized by a high volume of domestic and international flights, a complex airspace geometry encompassing three of the nation's busiest airports, and dense traffic flow along the northeast corridor. Failure of an ACF, though highly unlikely, would have a potentially

far-reaching impact on the movement of air traffic, both regionally and nation-wide. One of the functions envisioned for the MCF is to mitigate the effects of such a failure by separating a portion of the terminal operations into a distinct facility. The present study will examine the relationship between the MCF configuration (in terms of which TRACONs it contains) and the impact of an ACF or MCF failure. A tradeoff may be hypothesized between the size of the MCF and its effect on the two types of facility failures. A greater role for the MCF would imply a greater mitigating effect in the event of an ACF failure and, conversely, a more serious effect for a failure of the MCF itself. This study will test that hypothesis.

Failure of an ACF could result from a variety of events. These range from equipment failure, which would probably be of brief duration, to natural disasters such as an earthquake, fire, or hurricane, whose effects would be felt for an extended time period. For the current study, the latter type of catastrophe is hypothesized, with the New York ACF disabled for a minimum of 3 days. It is also assumed that all personnel and controllers are available to work at backup facilities after the failure. The time of failure is set at 5:00 p.m. on a weekday, a worst case scenario.

In the event of an ACF failure, a contingency plan goes into effect. Adjacent ACFs, Washington, Cleveland and Boston, along with the proposed Capitol MCF, take control of a predesignated portion of the failed airspace. The additional workload imposed on the adjacent centers limits their ability to control en route traffic in the New York area. Therefore, an attempt would be made to reduce the flow of air traffic into the affected area, thereby ensuring adequate separation of aircraft. This would be achieved by the imposition of Estimated Departure Clearance Times (EDCTs) by the Central Flow Control Facility (CFCF) to delay aircraft on the ground whose destination is within the ACF's boundary. Aircraft transitioning the failed airspace could be rerouted around it or held outside the affected sectors. Airborne flights heading towards airports within the ACF could similarly be held at the boundary or directed to other airports. Departing flights within the failed boundary would be held on the ground until the situation was stabilized. Airborne flights within the ACF boundary would be allowed to proceed to their destinations.

Personnel from the New York and adjacent ARTCCs and TRACONs, as well as ATR-310, AOR-100, and ACD-340, met at the FAA Technical Center in September 1990 to define the parameters for the current study. The meeting produced a plan for partitioning ACF-controlled sectors among the backup facilities in the event of an ACF failure. Representatives from the backup facilities estimated the capacities at which they could handle traffic in each sector, for both the short term (3-36 hours) and long term (beyond 36 hours).

Table 1 shows the sectors which would be controlled by each facility after an ACF failure and the post-failure capacity estimates for each sector.

The New York, Washington, and Boston MCFs will be defined so they share common boundaries. Traffic flying between airports in these areas may not be directly affected by the ACF failure if they use MCF airspace (they will not receive EDCTs) under Visual Meteorological Conditions (VMC). Commuter aircraft may proceed in Visual Flight Rules (VFR) up to the MCF boundary and call the MCF for either a VFR or Instrument Flight Rules (IFR) clearance through the Terminal Control Area (TCA).

TABLE 1. ASSIGNMENT OF NY ACF SECTORS TO BACKUP FACILITIES AND SHORT TERM CAPACITIES AFTER ACF FAILURE

ZOB	ZBW	ZDC	DC MCF
Sector Capacity	Sector Capacity	Sector Capacity	Capacity
34 = 35%	42 = 50%	9 = 50%	PHL = 20%
49 = 50%	56 = 50%	10 = 50%	ABE = 20%
75 = 50%	86 = 35%	11 = 25%	WRI = 20%
73 = 35%	35 = 30%	25 = 25%	
91 = 25%	36 = 30%	26 = 25%	
93 = 25%	50 = 30%	27 = 25%	
74 = 25%	51 = 25%	39 = 30%	
	66 = 20%	55 = 30%	
		92 = 25%	
		67 = 55%	
		68 = 55%	

Long Term (>36 hrs post-failure) capacity of all en route sectors: 100%

3.3 NEW YORK MCF FAILURE.

The New York TRACON facility has several unique aspects. It is the busiest facility of its kind in the nation, handling over 1.7 million instrument operations in 1988 [3]. The facility serves Kennedy, LaGuardia, and Newark airports and scores of satellite airports, providing approach and departure control and en route service in a 15,000 square mile area. Sometimes referred to as the New York "Common Eye" or N90, the facility consolidates several TRACONs (LaGuardia, Kennedy, Newark, and Teterboro), as the MCFs will do. The FAA has been studying alternative plans for apportioning the New York airspace between the future ACF and MCF and has been defining the relationships among the New York, Boston, and Washington facilities in the event of facility failure.

The three alternative MCF configurations to be considered in this study are:

1	2	3
N90	N90	N90
	PHL (Philadelphia)	PHL
	WRI (McGuire AFB)	WRI
	ABE (Allentown)	ABE
		AVP (Wilkes-Barre)
		RDG (Reading)

Figure 1 depicts these and other TRACONs within Washington ARTCC (ZDC), Boston ARTCC (ZBW), New York ARTCC (ZNY), and Cleveland ARTCC (ZOB). The TRACONs considered in the above configurations were assumed to retain their present lateral boundaries but assumed a common ceiling of 17,000 feet.

For the first of the proposed configurations, in the event of an MCF failure, the New York ACF would back up the entire MCF. For the second configuration, the New York ACF would back up N90 and Allentown (ABE), while the Capitol MCF would cover the Philadelphia (PHL) and McGuire AFB (WRI) terminal areas. In the third configuration, New York ACF would back up N90, ABE, AVP, and the Capitol MCF would provide back up for PHL and WRI.

Commuter aircraft during an MCF failure would be able to fly VFR to the airport, but would not receive radar service from the facility backing up the failed MCF. The aircraft would have to fly beneath the floor of the TCA, which normally becomes increasingly lower as an aircraft approaches the airport. Commuters would rely on the tower to issue the TCA clearance from a distance of about 5 to 10 miles from the airport.

3.4 SCENARIO DEFINITIONS.

Six scenarios were modeled. The main conditions are an ACF failure with MCF intact and an MCF failure with ACF intact. For each of the two conditions, three different configurations were considered. The configurations for the MCF are given in section 3.3. In all the scenarios, failure occurred at the peak traffic time. All scenarios will model a VMC day only. A matrix showing the different scenarios is given in table 2.

3.4.1 Modeling New York ACF Failure.

A day by day description of the failure scenario for a 3-day period and the modeling of the associated events are as follows:

Within the first 2 minutes CFCF would place a hold on all departures in the Continental United States (CONUS); 4 minutes after the failure adjacent centers would disallow flights to

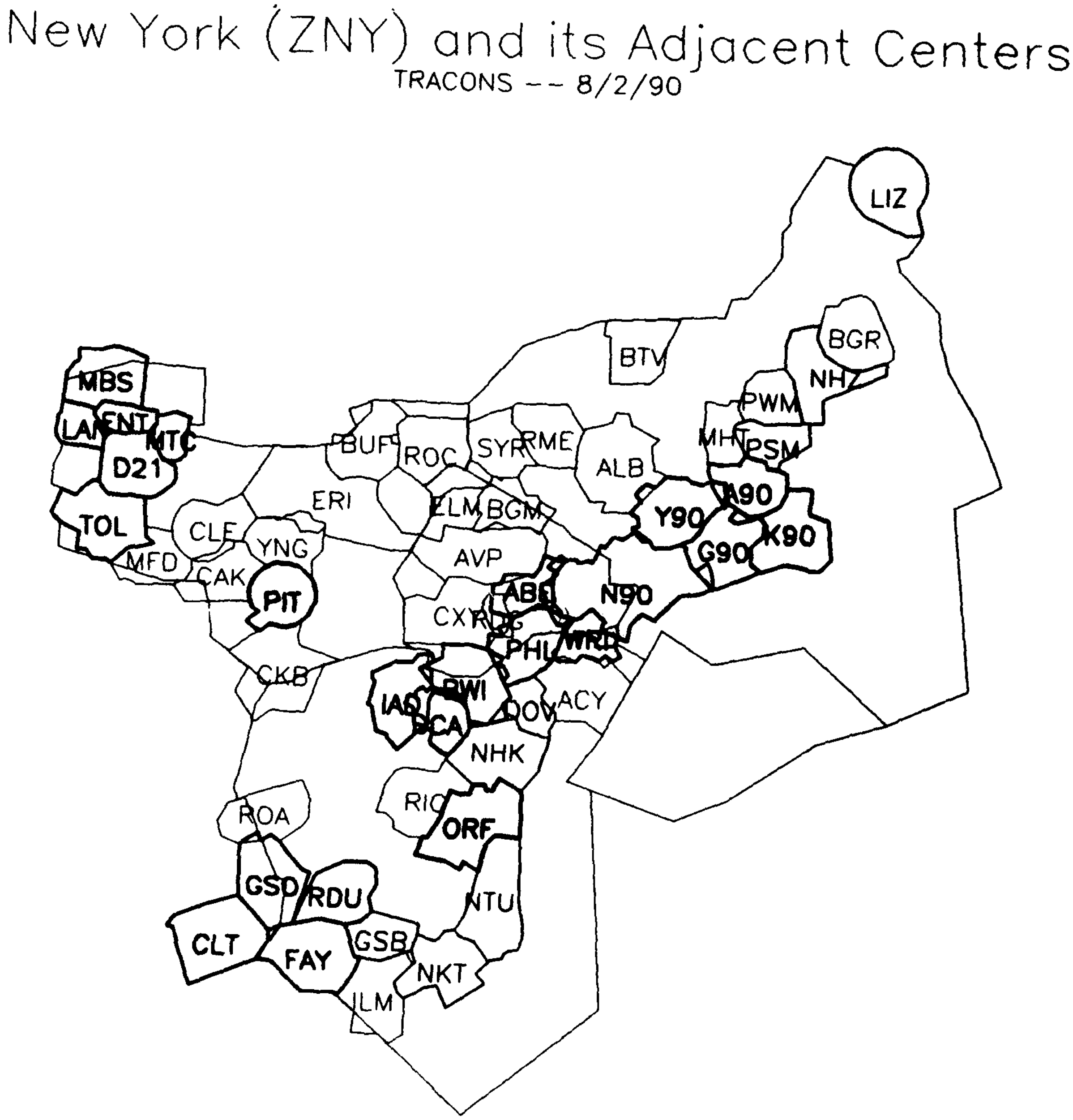


FIGURE 1. NORTHEASTERN TRACONS

TABLE 2. SCENARIO DEFINITIONS

MCF CONFIGURATION

	Config. 1 (N90)	Config. 2 (N90,PHL,ABE, WRI)	Config. 3 (N90,PHL,ABE, WRI,AVP,RDG)
ACF Failure	ACF Backup by Adjacent ACFs And Capitol MCF	ACF Backup by Adjacent ACFs	ACF Backup by Adjacent ACFs
MCF Failure	MCF Backup by NY ACF	NY ACF Backs Up N90, ABE; Capitol MCF Backs Up PHL WRI.	NY ACF Backs Up N90, ABE AVP, RDG; Capitol MCF Backs Up PHL,WRI

traverse the failed boundary. Ten minutes after failure the backup centers would start releasing flights to pass through the failed airspace, ensuring adequate spacing between the flights. It was assumed that the adjacent centers would initially be able to provide only 10 percent of the New York ACF normal capacity. The reduction in airspace capacity, in the ACF failure scenarios, was modeled by placing restrictions around the failed airspace boundary.[2] Therefore, the restriction boundary around the ACF was set to reduce the traffic flow to 10 percent. Also at 10 minutes after failure, EDCTs were activated and flights heading to the failed ACF were spaced by the EDCT program, reflecting the reduced capacity. Airport Acceptance Rates (AARs) at the airports within the failed ACF were reduced to 10 percent of the normal VMC airport arrival capacity in the EDCT program. Departures were set the same as the AARs. The EDCT program was modified to exclude commuter flights whose destination is New York from receiving EDCTs. Since commuters may fly entirely within the contiguous MCF airspace, EDCTs are not necessary.

[2] Trial simulation runs were made to determine the feasibility of using reduced sector capacities instead of a restriction boundary to model the ACF failure event. Sector capacities simulate, more directly, the events being modeled and also restrain traffic internal to the ACF boundary, while the restrictions do not. As noted in section 1, however, sector capacities have not, in general, been used successfully in previous NASPAC studies. An attempt was made to circumvent the problem of inaccurate sector capacity values by using default throughput values for the ZNY sectors, obtained from a baseline run of the model, as the instantaneous and hourly capacity values. Preliminary tests, however, produced excessively high delays which were attributed to sector deadlock. This approach was, therefore, abandoned.

Forty minutes after the failure of the New York ACF, the capacity of the airspace was assumed to increase to 20 percent. The ACF boundary restriction was adjusted accordingly. The AARs in the EDCT program also increased to 20 percent. At this time, the New York area airports allowed departures at the 20 percent rate. The departure rate is limited by the capacity of the surrounding en route airspace and not by the airports themselves or the terminal areas.

Three hours after failure the capacities of the sectors within the failed airspace increased to the levels shown in table 2 and stabilized at that level for the rest of the day. AARs were set at 35 percent in the EDCT program. On the second day, it was assumed that the capacity remained at the same levels throughout the day, allowing the backup controllers to become familiar with the situation. On the third day, with the controllers from the failed ACF working at the adjacent facilities, it was assumed that the capacity would increase to 100 percent of normal. The summary of the failure scenario is shown in table 3.

3.4.2 Modeling New York MCF Failure.

The reduction in airspace capacity following an MCF failure was modeled in the same manner as the ACF airspace - using restriction boundaries.[3] This allows the airports to function at their full arrival capacities with access limited by the airspace restriction. The MCF restriction boundaries correspond to the TRACON boundaries and are assigned the appropriate throughput limiting values after the MCF fails. Failure of the New York MCF was modeled by reducing the corresponding restriction boundary capacities to the levels shown in table 4.

For the first of the MCF configurations (N90 only), following an MCF failure, the capacity of the terminal airspace was reduced to 10 percent of normal for the first day of the failure. On the second day after the event, capacity remained at the same level and was increased to 50 percent on the third day. For the other two options, N90 had the same short term capacity after failure (10 percent). The long term capacities were 45 percent for Configuration 2 and 40 percent for Configuration 3. Other capacities for N90 and other terminal areas under the three conditions are given in table 4.

[3] Failure of the New York MCF was initially modeled by reducing the corresponding airport capacities to the levels shown in table 4. This methodology was used by MITRE in the Chicago ACF Failure Analysis. Restriction boundaries were not used initially due to time constraints and the greater complexity in the modeling process. Use of restrictions, however, is more consistent with the ACF method and more realistic since both types of facility failures represent an airspace management problem and not an airport capacity problem. The restriction boundary method was adopted and the results are presented in section 5. Results based on using reduced airport capacities are presented in appendix A.

TABLE 3. SUMMARY OF EVENTS FOR MODELING ACF FAILURE

Time After Failure (Minutes)	All Airports Departure Capacities	ZNY Inbound Restrictions	ZNY Airports Departure Capacities	Airport Arrival Rate (AAR)	EDCT To ZNY Airports
DAY 1					
2	Shut Down(1/HR)		Shut Down(1/HR)	100% for MCF Airports	
4		Shut Down(1/HR)		20% at PHL, ABE, WRI, AVP, RDG for opt 1	
10	Turn On@100% (with EDCTs to ZNY APs)	Turn On@10%*	Stay Shut Down	20% at RDG, AVP for opt 2	On @10% of AAR (limits air-space use)
40		On@20%*	On@20% (based on airspace constraints)		On @20% (limits air-space use)
180		Individual Sector Capacities (Table 2)	On@35% (based on airspace constraints)		On @35% (limits air-space use)
DAY 2 (Same as 180 Minutes)					
DAY 3 = 100% Capacity					
	Turn On@100% (with EDCTs to ZNY APs)	On@100%	On@100%	On@100%	

*% of baseline traffic flow rate

TABLE 4. ESTIMATED TERMINAL AREA CAPACITIES AFTER NY MCF FAILURE

(Short Term/Long Term)

	Config. 1	Config. 2	Config. 3
N90	10/50%	10/45%	10/40%
ABE	N/A	10/45%	10/40%
PHL	N/A	20/25%	20/25%
WRI	N/A	20/25%	20/25%
AVP	N/A	N/A	10/40%
RDG	N/A	N/A	10/40%

The low short term capacity value (10 percent) is a result of the highly complex nature of the New York TRACON airspace. Representatives from the facilities involved judged this to be the maximum capacity that could be handled by backup controllers not familiar with the details of the airspace.

3.5 CHANGES TO THE NASPAC MODEL.

The NASPAC simulation, preprocessor, and databases were modified for this study. The following is a partial list of changes performed:

a. Modification of EDCT module to allow cancellations.

b. Modification of EDCT module to exclude commuter flights to New York from receiving EDCTs.

c. Addition of the restriction boundary to the restriction database and Change Restriction files.

d. Addition of New York satellite airports to the model (ABE, AVP, RDG, WRI).

e. Modification of simulation code to handle dynamic changes in sector capacity.

f. Generation of a change-airport-capacity files for scenario definitions.

3.6 ASSUMPTIONS.

A partial list of design assumptions follows:

a. Airspace capacities for the post-failure scenarios are assumed to be reasonably accurate.

b. Present-day (1989) demand, capacity, and ATC procedures are modeled, unless otherwise stated.

c. ACF boundaries correspond to current ARTCC boundaries.

d. Rerouting and diversions are not modeled.

e. Failure of an ACF (MCF) is assumed to occur at the peak time to study a worst case scenario.

f. VMC conditions prevail throughout the entire failure and backup activation scenario.

g. No simultaneous failures of both MCF and ACF are assumed.

h. Once the failure occurs, the facility stays down for the duration of the simulation.

i. This study examines capacity effects only. Other factors which may be involved in determining optimal MCF size, such as safety considerations, are not addressed.

4. METHODOLOGY.

4.1 METRICS.

4.1.1 Delay.

Several measures of delay were collected during the simulation. These included technical and effective delays. Technical delay represents the time spent waiting for system resources. In the NASPAC model, aircraft are queued while waiting for resources such as arrival and departure fixes, airports, and airspace. Effective delay is the difference between scheduled arrival time and actual arrival time and reflects cumulative delays across flight legs during the simulation period.

NAS-wide delay statistics were used to gauge effects of the various failure scenarios on the entire NAS. Delay and throughput were measured for the 58 major airports in the model, including the three major airports in the New York area, Philadelphia, and the satellite and reliever airports included in the proposed MCF configurations.

Delays incurred at the restriction surrounding the New York ACF boundary were tallied. Sector capacities were turned off during the simulation, but sector throughput was collected.

4.1.2 Cancellations.

In the unprecedented event of a major ATC facility failure, many flights would undoubtedly be canceled. In the real world, under normal conditions, the decision to cancel a flight is based upon a complex set of factors including passenger demand, availability of other flights, competitors' actions, the lateness of the flight,

and the need to balance other cancellations. The NASPAC model does not generally model cancellations.[4] For the Chicago ACF study, cancellations were implemented in the EDCT module of the preprocessor and a 2-hour cancellation time was used. The same algorithm and cancellation criterion were used in the present study: flights delayed more than 2 hours during the simulation were canceled. When a flight was cancelled, all subsequent legs of the flight were cancelled as well.

4.1.3 Cancellation-Delay Equivalence.

In order to provide a common metric for comparison purposes, an attempt was made to express cancellations in terms of equivalent minutes of delay. The EDCT module was executed twice for each scenario: once with the cancellation code and once without it. The difference in total EDCT delay between the two conditions (with and without cancellations) was calculated. (The total EDCT delay is lower with cancellations in place, since the canceled flights do not receive EDCTs.) The difference in delays was divided by the number of cancellations to derive the delay-per-cancellation estimate. The cancellation-delay equivalence is dependent on capacity and other scenario-specific variables. Different cancellation-delay equivalences result from the different scenarios. This cancellation-delay equivalence was calculated for each simulated day for every configuration and is shown in table 5.

While the 2-hour cutoff for cancellations is a simplification, MITRE found in the Chicago ACF study that the cancellation-delay equivalence did not vary much with the time at which cancellations were invoked. The same factor was investigated in the present study. EDCT runs were performed on the MCF failure Configuration 2, day 3. The following results were obtained.

EDCT delay with no cancellations: 353613 minutes of delay

EDCT delay with the following cancellation times:

Cancellation Time:	Cancellation-Delay Equivalence:	
1 hour	668.6 min*	(458 cancellations, 47374 min)
2 hours	682.2 min	(378 cancellations, 95744 min)
3 hours	703.4 min	(304 cancellations, 139790 min)
5 hours	729.3 min	(199 cancellations, 208478 min)

*min = minutes

[4] Cancellations will be implemented in release R2.

TABLE 5. CANCELLATION-DELAY EQUIVALENCE BY SCENARIO

ACF Failure

Day \ Config	1	2	3
1	612 minutes	641 minutes	641 minutes
2	717 minutes	691 minutes	691 minutes
3	764 minutes	-------	-------

MCF Failure

Day \ Config	1	2	3
1	523 minutes	516 minutes	516 minutes
2	556 minutes	616 minutes	635 minutes
3	576 minutes	682 minutes	688 minutes

These results support the finding that cancellation delay equivalence does not vary much when the cancellation threshold is increased. There is a modest positive correlation between the two.

4.1.4 Common Metric.

"Total System Delay" is used as a common metric for comparison purposes. It is calculated using the following formula:

Total System Delay = [System Technical Delay + Total EDCT Delay + (Cancellation-delay Equivalence X Number Cancellations)]

4.2 ESTIMATION OF AIRSPACE RESTRICTIONS.

The reduction in airspace capacity was modeled as an inbound boundary restriction. Depending on the configuration, the inbound boundary restriction surrounded a specific area of the ACF or MCF. The three separate MCF configurations analyzed in this study resulted in three sets of restriction boundaries.

Using a restriction boundary models the delays incurred by an aircraft entering the failed airspace; however, it does not model the arrival delays incurred by aircraft operating totally inside the airspace boundaries. It was assumed that the error associated with this limitation is small.

The flow rate across the restriction boundary varied according to the individual sector which abuts the ACF boundary, corresponding to the capacities in table 2. Flow rates used in the MCF failure were based on the capacities shown in table 4. These capacities were estimated by operational personnel from the affected facilities. Though flights are more likely to be vectored, slowed, or put in a holding pattern, for modeling purposes the flights wererestricted or held at the ACF boundary. This is an inherent limitation of the NASPAC model. Arriving aircraft within the failed airspace at the time of the failure were allowed to proceed and land. En route aircraft crossing the failed airspace were held at the boundaries of the failed airspace. Airborne aircraft within the failed airspace were allowed to exit.

The initial step in the development of the airspace restriction boundary was to establish a baseline or prefailure (normal conditions) maximum hourly throughput for each restriction line. This was accomplished by allowing an unlimited number of aircraft to fly across a restriction line. The simulation was run and the maximum hourly throughput, or flow, measured in terms of aircraft per hour, was recorded. This value was then translated into an average spacing value (minutes in trail between aircraft). The baseline spacing value was obtained by dividing the maximum hourly throughput for the restriction line into sixty. This value was then multiplied by the percentage restriction value to obtain the restriction flow or service rate for the restriction segment.

The ACF airspace boundary was modeled using 15 restriction segments. The restriction extended from ground level to 60,000 feet. No restriction segment existed where the New York MCF boundary adjoined the Capitol MCF boundary. It was assumed that a corridor existed between the two adjacent MCFs to allow tower en route traffic.

The MCF airspace configurations were also modeled using restrictions. Figure 2 shows the approximate airspace boundary of the various MCF configurations.

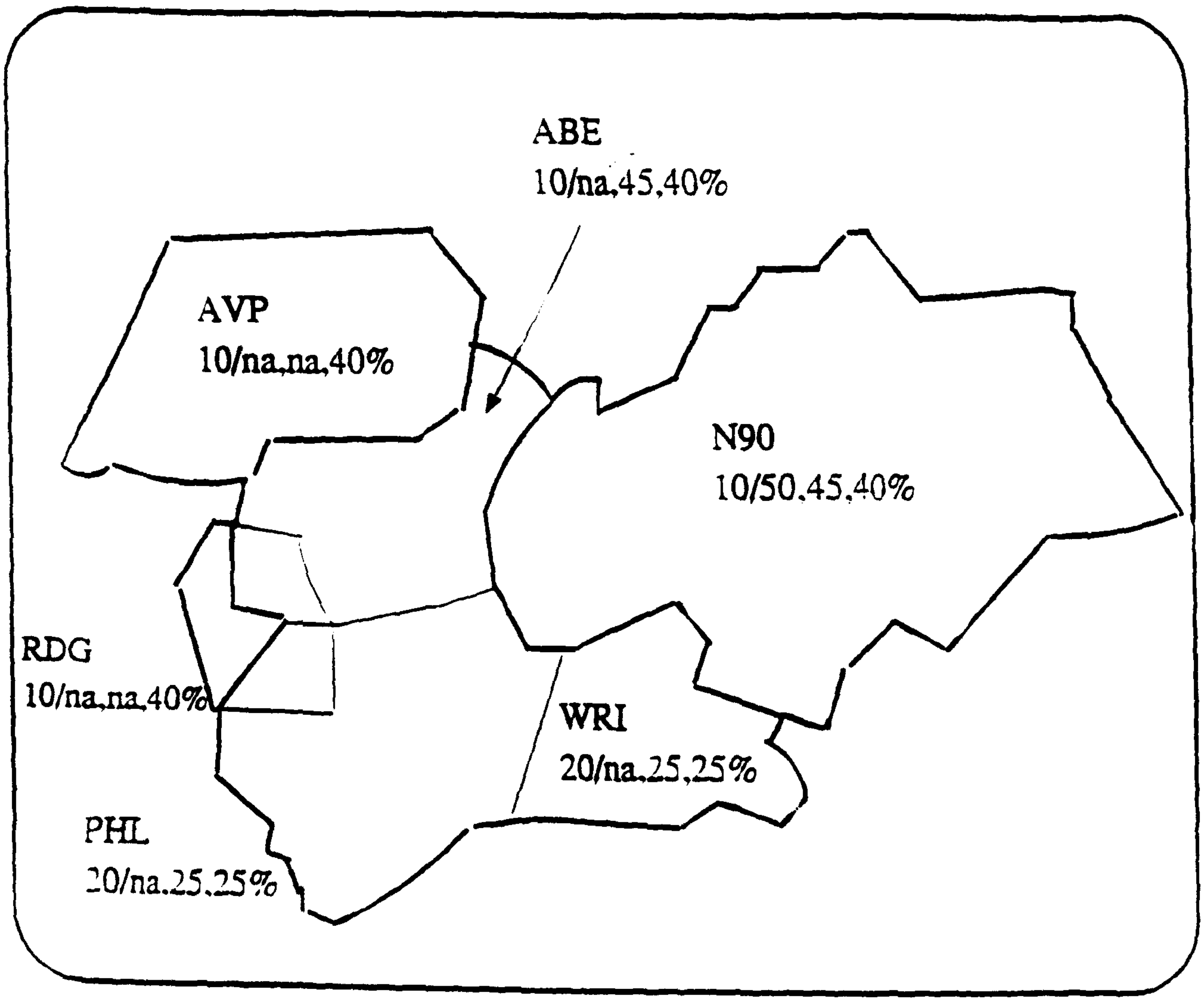
4.3 COMMUTER FLIGHT EDCTS.

Commuter flights were exempted from receiving EDCTs. This was based on the assumption that commuters will choose to fly under VFR through the failed airspace on a VMC day. Also, for the ACF failure, the contiguous MCF boundaries would allow many commuters to circumvent the failed airspace. Exempting commuters from the EDCT program also mitigates the effects of canceling all subsequent flight legs of an itinerary that follow a canceled flight leg. This limitation in the model unfairly reduces commuter traffic loading since regional airlines fly back and forth several times each day between the major airport hub and small outlying airports.

A sensitivity analysis was performed to investigate the impact of not issuing EDCTs to commuters. Simulation runs were made for the first 2 days of failure for Configuration 1 with and without EDCTs to commuters. For the ACF failure, issuing EDCTs to commuters resulted in a 3 percent reduction in technical delay on day 1 and a 10 percent reduction in technical delay on day 2. This was offset by the increase in cancellations: 10 percent for day 1 and 13 percent for day 2. When the delay-equivalence value was factored into the analysis, the overall impact was an increase in delay of 3 to 4 percent when EDCTs were issued to commuters.

For the MCF failure, issuing EDCTs to commuters resulted in a 6 percent decrease in technical delay on day 1 and a 10 percent decrease on day 2. Cancellations increased 10 percent and 12 percent, respectively. Factoring in the delay equivalence resulted in an increased delay of approximately 1 percent.

Exempting commuter flights from receiving EDCTs resulted in fewer cancellations, smaller ground delay, and a corresponding increase in technical delay. System technical delay increased since there was an increase in demand (i.e., the commuter flights). The increase in technical delay was relatively greater for the MCF failure scenarios than for the ACF failure scenarios. This is attributed to the ACF modeling technique. The ACF restriction boundary was drawn so that the terminal areas representing the proposed New York MCF adjacent to functioning airspace were not



CONFIGURATION 1 = N90
2 = N90 + PHL + WRI + ABE
3 = 2 + RDG + AVP

Notation : Short term/Long term Config 1, Config2, Config3

FIGURE 2. TRACONS COMPRISING POSSIBLE NY MCF

receive delays. This was an attempt to model the contiguous MCF boundaries in the northeast corridor. Some portion of the commuter flights (ideally, all of them) were, therefore, not subject to this source of delays for the ACF failure.

For the MCF failure scenarios, the commuter flights exempted from EDCTs were, without exception, subject to delays at the New York airports impacted by the MCF failure. Therefore, little difference was expected between the total delay for the MCF failure with or without EDCTs issued to commuters. The additional cancellations should balance out the smaller technical delay. A difference of less than 1 percent was found. Ideally, the simulation should have been modified to more accurately model cancellations for commuter flights, but the sensitivity analysis indicates only minor differences resulted in any case.

4.4 CONDUCT OF SIMULATION AND STOCHASTIC CONSIDERATIONS.

Three simulation runs are required for each scenario - one run for each day for a 3-day period. Each scenario models 72 hours of real time. Each scenario consists of a failure type (ACF or MCF) and one of three possible MCF configurations (each configuration having a unique set of TRACONs). Table 1 gives the scenario definitions.

Repeated trials were conducted to account for the presence of stochastic elements in the simulation. Since this study assumed a VFR day, a major source of variability was eliminated. Stochastic elements in this analysis are aircraft en route flight times, assigned route (from Host-Z data), and the unscheduled VFR general aviation and military demand. Previous analysis of stochastic variability (with the components modeled in this analysis) has shown that the results normally differ by no more than 5 percent. Examination of the multiple runs in appendix C shows this observation holds true for this study.

A recent MITRE briefing on "Number of Runs Analysis" stated that "a 99 percent confidence interval (CI) for system-wide technical delay requires three runs" [4]. If analysis is by airport then the number of runs required is much larger (9 for a 95 percent CI; >11 for a 99 percent CI). MITRE has suggested making at least three runs with additional runs performed until reasonable confidence intervals are obtained for output metrics of interest (e.g., more runs are required if presenting results by airport). Where the size of the difference between scenarios is of primary interest and not the value of the metric, then the number of runs need not be as extensive as specified above. The MITRE analysis included pushback delays as one of the four stochastic elements. Pushback delays were not included in the current study.

System technical delay is the key metric for this study with the primary objective to differentiate between the MCF configurations modeled. Three runs were made per scenario. The EDCT delays and

cancellations within the same scenario are not affected by the stochastic elements. The difference in total system delay between Configuration 1 and Configuration 2 far exceeded the stochastic variability among the stochastic runs for the same configuration. This reduced the need for an excessive number of runs to produce reliable results without major concern for statistical variability.

5. RESULTS AND CONCLUSIONS.

5.1 SUMMARY OF RESULTS.

System-wide delay was compared among the different MCF configurations for each type of failure. Multiple runs were performed and the average technical delay was recorded. Table 6 shows the results of the New York ACF failure across each of the MCF configurations. Table 7 shows the results of the New York MCF failure. These data show EDCT (ground) delay in minutes, the number of cancellations, and system technical delay in minutes. The system technical delay is the total of terminal delay (arrival and departure), delay incurred by standard in-trail restrictions, and the delay encountered by aircraft at the New York ACF or MCF airspace boundary. These data are combined in the common metric "Total System Delay" defined in section 4.1.4.

Table 8 is a "Decision Table" which presents the "Total System Delay" over a 60-day period. Since the MCF failure does not return to 100 percent of its original capacity within the time period modeled as does the ACF failure, an extended time period is used for comparative purposes. Only 3 days were actually simulated for each configuration, so the 60-day totals represent the sum of the Total System Delay for days 1 and 2 and 58 times the Total System Delay for day 3.

5.2 DISCUSSION OF RESULTS.

For the ACF failure, expectations are that delay should decrease when more TRACONs are included in the MCF. Results confirm this. The general trend for total system delay across configurations (for each day) is downward. Examination of day 2 for Configurations 2 and 3 shows an increase in the system technical delay in comparison to Configuration 1. The key factor appears to be the inclusion or exclusion of the Philadelphia TRACON in the MCF configuration. Since Philadelphia is in the MCF instead of the ACF in Configuration 2, the EDCT program was not invoked. As a result, the number of cancellations between Configuration 1 and Configuration 2 is reduced dramatically (723 cancellations to 458 cancellations). Since Philadelphia traffic is not metered by EDCTs the additional traffic loading and stochastic arrival pattern results in increased system technical delay. Factoring in cancellation-delay equivalence and EDCT delay yields the expected results.

TABLE 6. SUMMARY ACF FAILURE DELAYS

ACF Failure

Day \ Config	1	2	3
1	238502 min T.D. * 319 Cancellations 29139 min EDCT Delay **Total**=462869**	240097 min T.D. * 246 Cancellations 20593 min EDCT Delay **Total**=418376**	239019 min T.D. * 246 Cancellations 20555 min EDCT Delay **Total**=417260**
2	310175 min T.D. * 723 Cancellations 80346 min EDCT Delay **Total**=908912**	339084 min T.D. * 458 Cancellations 59025 min EDCT Delay **Total**=714587**	327627 min T.D. * 458 Cancellations 58917 min EDCT Delay **Total**=703022**
3	114743 min T.D. * 265 Cancellations 21429 min EDCT Delay **Total**=338632**	96630 min T.D. * 0 Cancellations 108 min EDCT Delay **Total**=96738**	96428 min T.D. * 0 Cancellations **Total**=96428**

* Technical delay averaged over four stochastic runs

**Total = Technical delay + Cancellation delay equivalence (612 - 764 min depending on scenario x number cancellations) + EDCT Delay

TABLE 7. SUMMARY MCF FAILURE DELAYS

MCF Failure using restriction boundary

Day \ Config	1	2	3
1	340269 min T.D. * 375 Cancellations 13426 min EDCT Delay Total** = 549820	358748 min T.D. * 444 Cancellations 24217 min EDCT Delay Total ** = 612069	358766 min T.D. * 444 Cancellations 24404 min EDCT Delay Total** = 612274
2	747626 min T.D. * 982 Cancellations 28999 min EDCT Delay Total**= 1322617	852889 min T.D. * 1212 Cancellations 54594 min EDCT Delay Total**= 1654075	844140min T.D. * 1212 Cancellations 55137 min EDCT Delay Total**= 1668897
3	224648 min T.D. * *125 Cancellations* 61708 min EDCT Delay Total**= 358356	323041 min T.D. * 378 Cancellations 95744 min EDCT Delay Total**= 676581	313809 min T.D. * 464 Cancellations 96251 min EDCT Delay Total**=729292

* Technical delay averaged over three stochastic runs

**Total = Technical delay average + Cancellation delay equivalence (516-688 min depending on secnario x number cancellations)+ EDCT Delay

TABLE 8. DECISION TABLE

Random Event \ Action	a1 Implement Config 1	a2 Implement Config. 2	a3 Implement Config. 3
θ_1 MCF failure	22,657,085 minutes *	41,507,842 minutes *	44,580,107 minutes*
θ_2 ACF failure	21,012,446 minutes *	6,743,767 minutes*	6,713106 minutes*
Totals:	43,669,504 minutes	48,251,609 minutes	51,293,213 minutes
MCF/ACF Ratio:	1.08	6.15	6.64

* Delay = Total System Delay** for Day 1 + TSD **for Day 2 + (TSD**for Day 3) *58

** Total System Delay = Total System Technical Delay + EDCT Delay + (Number of Cancellations * Cancellation-Delay Equivalence for each scenario)

There is little difference in total delay generated during the ACF failure for Configurations 2 and 3. The MCF Configuration 3 includes two additional TRACONs - Wilkes-Barre (AVP) and Reading (RDG). For Configuration 3, EDCTs were not generated for these airports during the ACF failure. As a result, EDCT delays decrease as expected. Cancellations remain unchanged since no flights destined for these airports were ever delayed more than the 2 hours required for cancellation. Due to the low traffic demand at these airports, system technical delay did not appreciably differ.

For the MCF failure, expectations were that delay should increase when more airports are included in the MCF. This holds true between Configurations 1 and 2. The dramatic increase in delay and cancellations between Configuration 1 and Configuration 2 is primarily a result of having Philadelphia included in the MCF in Configuration 2. The high traffic demand and low capacity following an MCF failure adversely impacts the system, dramatically increasing delay. Examination of table 4 also shows that the restrictions for the Philadelphia and McGuire airspace are more limiting than for the N90 airspace (45 percent versus 25 percent). For configuration 2 the PHL and WRI restriction boundary becomes the area boundary and throughput into N90 airspace from the south is restricted by 25 percent -- not the 45 percent seen in Configuration 1.

The magnitude of the delay associated with an MCF failure far exceeds the delay incurred with an ACF failure. This is a function of the input parameters chosen for the study. The initial limiting capacity following an MCF failure is 10 percent of the baseline traffic flow and does not improve at the rate seen with an ACF failure. TRACONs within the MCF are not assumed, within the time-frame modeled, to return to 100 percent capacity. In fact, they never reach more than 50 percent of their original values.

Table 8 is a "Decision Table" and tabulates the delay over a 60-day period for each configuration. If the assumption is made that either an ACF or MCF failure is equally likely, then MCF Configuration 1 is the most logical choice. This selection can be justified using several different decision criteria.

One approach is to evaluate the results shown in table 8 using the principles of game theory. In game theory, players seek to maximize the damage they can do to the opposing player and minimize the damage done by their opponent. It is also assumed that the opponent is fully knowledgeable; each player knows the value of the outcomes and knows the choices made by his opponent. In this situation, the best defensive strategy is to choose the option that minimizes the maximum damage that can be inflicted by the opponent. This theory, when applied to the current case, means that the defensive player chooses the MCF configuration that will minimize the maximum damage that can be done. (If a terrorist had a choice between creating an ACF or MCF failure, he would choose the one

that would create the most damage - maximize the delay.) The defensive strategy is to first identify the worst case for each configuration (for each configuration, identify the worst outcome in the event of a failure) and then choose from among these the configuration that has the lowest delay. In effect, choose the configuration that prevents the opponent from doing the most damage -- minimax principle. Examination of table 8 shows that the worst case for each configuration is always the MCF failure. Since Configuration 1 (N90 airports only) minimizes the impact of an MCF failure, the minimax strategy suggests this as the logical choice.

Another decision method is to simply sum up the delays for each configuration and choose the configuration with minimum total delay. Examination of the totals at the bottom of table 8 again results in choosing Configuration 1. Other criteria can be used (e.g., expected value, etc.). Tables 6, 7, and 8 should provide sufficient information for analytical based decisions.

5.3 CAVEATS.

The results of this analysis must be interpreted in the light of the assumptions and parameters used in the analysis:

a. The results are very sensitive to the input parameters defining the airspace capacity. These parameters resulted in the MCF failure being more severe than the ACF failure. The values used are the result of coordination among FAA field, headquarters, and FAA Technical Center personnel.

b. The modeling approach did not include rerouting and diversions. The delays incurred at the airspace boundary restrictions are assumed to be a surrogate measure of the overall impact of the reroutes and diversions which would likely occur after a failure.

c. Flights totally within the airspace boundary incurred no arrival delays. This includes aircraft flights inside the airspace boundary at the time of failure. The error induced by this assumption is believed to be negligible.

d. This analysis considered only VMC weather conditions with all airports operating at or near their maximum capacity. It is assumed that reduced IFR capacities associated with airports outside the ACF would result in a reduced rate of aircraft entering the New York ACF before a failure. This would require a less severe EDCT program to protect the airspace after failure. The overall effect of an ACF failure with New York area airports under IMC is unknown. Results may be better or worse than the case analyzed.

e. Flights which received more than a 2 hour EDCT delay were canceled in the simulation. The model currently does not have an

algorithm that takes into account the various factors used by the airlines in deciding which flights to cancel - passenger loading, destination airframe requirements, crew rest requirements, airline schedule, and competitors' schedules. Furthermore, when a flight was cancelled, all subsequent legs of the flight were cancelled as well. This is an additional simplification which may (unrealistically) compound the effects of the cancellation.

f. Results are sensitive to the cancellation-delay equivalence value used to generate a common delay metric.

5.4 CONCLUSIONS.

The results are consistent with expectations based on the assumptions and parameters used in the model. The following conclusions can be drawn from analyzing the data.

Under the current constraints and assumptions and solely on the basis of vulnerability to failure, N90 represents the optimal configuration.

The major difference between configurations is attributable to the impact of traffic loadings at Philadelphia. It may be desirable to examine other MCF configurations which do not include Philadelphia.

The consequences of an MCF failure appear to be more catastrophic than an ACF failure. On the second day, total delay is nearly three times greater for the MCF failure than for the ACF failure. This is due to the low airspace capacity of 10 percent after the MCF failure. Moreover, the effects of the MCF failure persist for the long-term (greater than 3 days post-failure), whereas, the ACF returns to normal capacity levels by the third day. Therefore, it is recommended that future facility planning in the New York area should take into consideration the relatively greater impact of an MCF failure. Consideration should be given to the factors or conditions that generated the limiting capacity values used in the MCF failure analysis.

6. REFERENCES.

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APPENDIX A
SUMMARY RESULTS BASED ON MODELING MCF FAILURE WITH AIRPORT CAPACITY LIMITATIONS

MCF Failure using Airport Capaity Restrictions

(10% capacity)

Day \ Config	1	2	3
1	403914 min T.D. * 375 Cancellations 13426 min EDCT Delay Total** = 613465	418744 min T.D. * 444 Cancellations 24217 min EDCT Delay Total ** = 672065	358766 min T.D. * 444 Cancellations 24404 min EDCT Delay Total** = 672429
2	869953 min T.D. * 982 Cancellations 28999 min EDCT Delay Total**= 1444944	890931 min T.D. * 1212 Cancellations 54594 min EDCT Delay Total**= 1692117	892482 min T.D. * 1212 Cancellations 55137 min EDCT Delay Total**= 1717239
3	229854 min T.D. * 125 Cancellations 61708 min EDCT Delay Total**= 363562	266879 min T.D. * 378 Cancellations 95744 min EDCT Delay Total**= 620419	302661 min T.D. * 464 Cancellations 96251 min EDCT Delay Total**=718144

* Technical delay averaged over three stochastic runs

**Total = Technical delay average + Cancellation delay equivalence (516-688 min depending on secnario x number cancellations)+ EDCT Delay

Random Event \ Action	a1 Implement Config 1	a2 Implement Config. 2	a3 Implement Config. 3
θ_1 MCF failure	23,145,005 minutes *	38,348,484 minutes *	44,042,020 minutes*
θ_2 ACF failure	21,012,446 minutes *	6,743,767 minutes*	6,713,106 minutes*
Totals:	434,157.451 minutes	45,092,251 minutes	50,755,126 minutes
MCF/ACF Ratio:	1.10	5.69	6.56

* Delay = Total System Delay** for Day 1 + TSD **for Day 2 + (TSD**for Day 3) *58

** Total System Delay = Total System Technical Delay + EDCT Delay + (Number of Cancellations * Cancellation-Delay Equivalence for each scenario)

DECISION TABLE : DELAYS OVER 60 DAY PERIOD

(MCF FAILURE MODELED USING REDUCED AIRPORT CAPACITIES)

APPENDIX B

SUMMARY RESULTS BY NEW YORK AREA AIRPORTS

Summary Results By New York ACF Airports
(ACF Failure)

		Config. 1	Config. 2	Config. 3
Day 1	EWR	20478	21321	20852
	JFK	21978	23174	22933
	LGA	11110	11176	11094
	HPN	5007	5139	5062
	ISP	4257	4076	4099
	TEB	1673	1679	1673
	PHL	11053	7533	7248
	WRI	7	1	1
	ABE	228	141	144
	RDG	5	16	1
	AVP	37	34	14
	RESTRICTIONS*	43221	50278	50389
Day 2	EWR	43433	48050	48320
	JFK	3202	3052	2959
	LGA	12868	16437	16322
	HPN	1393	1028	1235
	ISP	612	589	638
	TEB	190	226	221
	PHL	5377	2629	2588
	WRI	19	1	1
	ABE	137	84	80
	RDG	149	17	4
	AVP	429	328	156
	RESTRICTIONS*	119931	147790	148017
Day 3	EWR	3743	3892	3962
	JFK	1961	1352	1352
	LGA	2853	3067	3165
	HPN	623	226	234
	ISP	306	165	159
	TEB	144	155	154
	PHL	27189	875	856
	WRI	27	1	1
	ABE	95	14	11
	RDG	155	31	1
	AVP	389	328	8
	RESTRICTIONS*	5989	5930	5844

+ Values are in minutes of Technical Delay averaged over all runs

* Delay Incurred at MCF bounday

Summary Results By New York ACF Airports
(MCF Failure)

		Config. 1	Config. 2	Config. 3
Day 1	EWR	44910	46048	45631
	JFK	65960	65726	65897
	LGA	24936	24600	25057
	HPN	18224	19404	13416
	ISP	13329	13904	25057
	TEB	4306	4110	4199
	PHL	1397	1321	1455
	WRI	1	1	.6
	ABE	12	90	89
	RDG	110	111	110
	AVP	10	61	85
	RESTRICTIONS*	77382	87450	88356
Day 2	EWR	93001	97467	97374
	JFK	41794	48844	52345
	LGA	87709	90149	90530
	HPN	84004	83238	83728
	ISP	86414	85835	86048
	TEB	52687	54508	53687
	PHL	1279	922	1059
	WRI	1	.3	.3
	ABE	301	394	526
	RDG	115	137	303
	AVP	6	160	440
	RESTRICTIONS*	213025	296016	282789
Day 3	EWR	10960	48373	63199
	JFK	706	1604	1601
	LGA	5854	8864	13185
	HPN	555	742	948
	ISP	279	640	739
	TEB	168	179	170
	PHL	1575	713	806
	WRI	1	0	0
	ABE	128	151	191
	RDG	1	102	102
	AVP	149	314	198
	RESTRICTIONS*	96349	141849	113072

+ Values are in minutes of Technical Delay averaged over all runs

* Delay incurred at MCF boundary

APPENDIX C
SYSTEM TECHNICAL DELAY STOCHASTIC RUNS

Results with different Random Seeds (ACF)

	Config.1	Config.2	Config.3
Day 1	Tot.Sys.Tech.Delay Run 1: 240715 Run 2: 237415 Run 3: 237378 Run 4: 238500	Tot.Sys.Tech.Delay Run 1: 240420 Run 2: 240518 Run 3: 240113 Run 4: 239337	Tot.Sys.Tech.Delay Run 1: 240390 Run 2: 238516 Run 3: 238603 Run 4: 238568
Day 2	Tot.Sys.Tech.Delay Run 1: 308277 Run 2: 310105 Run 3: 309501 Run 4: 312815	Tot.Sys.Tech.Delay Run 1: 335245 Run 2: 339705 Run 3: 336625 Run 4: 344760	Tot.Sys.Tech.Delay Run 1: 335232 Run 2: 325528 Run 3: 321202 Run 4: 328547
Day 3	Tot.Sys.Tech.Delay Run 1: 115928 Run 2: 115315 Run 3: 113755 Run 4: 113972	Tot.Sys.Tech.Delay Run 1: 97607 Run 2: 96283 Run 3: 96215 Run 4: 96415	Tot.Sys.Tech.Delay Run 1: 97321 Run 2: 96104 Run 3: 96003 Run 4: 96283

Results with different Random Seeds (MCF)

	Config.1	Config.2	Config.3
Day 1	Tot.Sys.Tech.Delay Run 1: 341919 Run 2: 340529 Run 3: 338360	Tot.Sys.Tech.Delay Run 1: 359450 Run 2: 357946 Run 3: 357264	Tot.Sys.Tech.Delay Run 1: 362093 Run 2: 358041 Run 3: 356164
Day 2	Tot.Sys.Tech.Delay Run 1: 750500 Run 2: 742621 Run 3: 749758	Tot.Sys.Tech.Delay Run 1: 854064 Run 2: 836078 Run 3: 836882	Tot.Sys.Tech.Delay Run 1: 844034 Run 2: 844035 Run 3: 844352
Day 3	Tot.Sys.Tech.Delay Run 1: 224186 Run 2: 222012 Run 3: 227748	Tot.Sys.Tech.Delay Run 1: 295218 Run 2: 296309 Run 3: 295994	Tot.Sys.Tech.Delay Run 1: 313680 Run 2: 314114 Run 3: 313633

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